NASA TECHNICAL NOTE

NASA TN D-7844

NASA TN D-7844

(NASA-TN-D-7844) MECHANICAL PROPERTIES OF SKYLAB THERMAL SHIELD MATERIALS AFTER PROLONGED ULTRAVIOLET IRRADIATION (NASA) 13 p HC $3.25 CSCL 11E

N75-12144

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MECHANICAL PROPERTIES OF SKYLAB THERMAL SHIELD MATERIALS AFTER PROLONGED ULTRAVIOLET IRRADIATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1974

1. Report No. D-7844	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Mechanical Properties of Skylab Thermal Shield Materials After Prolonged Ultraviolet Irradiation		5. Report Date November 1974
		6. Performing Organization Code 755
7. Author(s) Carl L. Haehner and Charles L. Staugaitis		8. Performing Organization Report No. G-7506
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		10. Work Unit No. 602-41-75-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

In response to an emergency request, the mechanical properties of two complex laminate materials, used as thermal shields on the Skylab spacecraft, were investigated. Concern over the prolonged use of these materials in the space environment prompted this investigation. Shields made of both of these materials, popularly called the parasol and the sail types, were taken to the Skylab spacecraft by the original Skylab astronauts. Both were used to restore thermal control after the original control surfaces were damaged during launch.

During the tests the tensile properties were measured at anticipated service temperature and after prolonged exposure to increasing degrees of ultraviolet radiation at intensities approaching two solar constants. Some samples received exposures equivalent to 2,350 hours.

The performance and degradation of the two materials are presented in terms of orientation, vacuum, and degree of irradiation. In general, the 75-μm (3-mil) parasol laminate showed a decrease in tensile properties as a function of exposure time, while the 200-μm (8-mil) sail laminate was little affected by exposure to the ultraviolet radiation.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Materials, Nonmetallic Space Vehicles Thermal Shield	Unclassified—Unlimited CAT. 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	10	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

This document makes use of international metric units according to the Systeme International d'Unites (SI). In certain cases, utility requires the retention of other systems of units in addition to the SI units. The conventional units stated in parentheses following the computed SI equivalents are the basis of the measurements and calculations reported.

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INTRODUCTION

On May 25, 1973, the Materials Engineering Branch and the Engineering Applications Branch, both of Goddard Space Flight Center (GSFC), responded to an emergency request from the Marshall Space Flight Center (MSFC) for support in testing Skylab's two thermal shield materials. As illustrated in figure 1, the 200-μm (8-mil) sail material was used successfully to restore thermal control to the orbital workshop of Skylab after extensive damage had occurred during launch to the original thermal control surfaces, including the loss of its meteoroid shield. The 75-μm (3-mil) parasol material thermal shield, installed first, did not provide sufficient thermal control. Both shields can be seen in figure 1, with the 200-μm (8-mil) sail material on top.

A principal objective of the materials investigation was to determine the change, if any, in the mechanical properties of the two types of complex laminated fabrics, referred to as parasol and sail materials, after prolonged exposure to ultraviolet (UV) radiation.

This effort by GSFC represented only one part of the cooperative emergency testing program, which also included the laboratories of MSFC, Lewis Research Center (LRC), and of a contractor. At GSFC the Engineering Applications Branch conducted life tests on various samples of the two laminated materials, submitted by MSFC, under UV radiation. At preselected intervals samples were removed for testing and for evaluating their mechanical properties.

MATERIALS

The parasol material consists of one layer each of woven orange nylon, mylar, and aluminum. The sail material has four layers; the top layer is of S-13-G thermal-control white paint and succeeding layers are of woven orange nylon, aluminum, and mylar, in that order.

Microscopic examination of the woven fabric reveals the nature of the weave of the orange nylon yarn. As shown in figure 2, there is a repeating pattern of what appears to be two heavier yarns.

OUTGASSING TEST

It is the practice of the Materials Engineering Branch to first screen, from an outgassing standpoint, all candidate materials for space applications. These tests are conducted in a

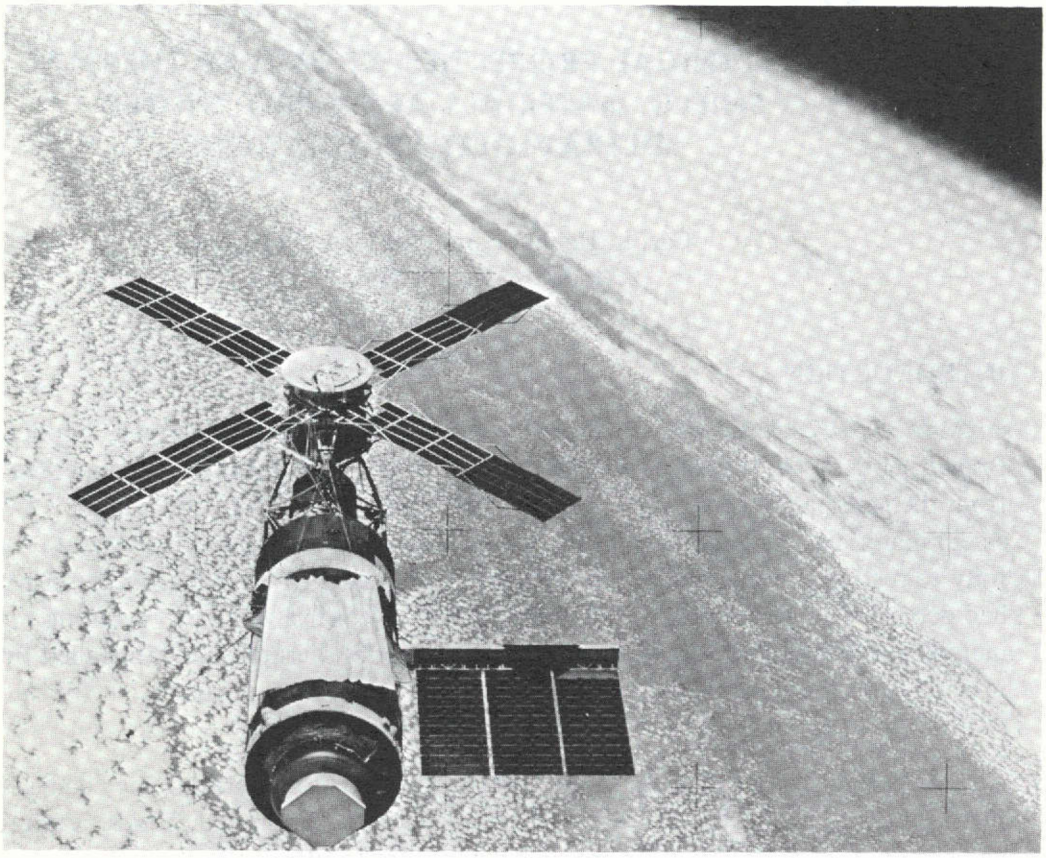
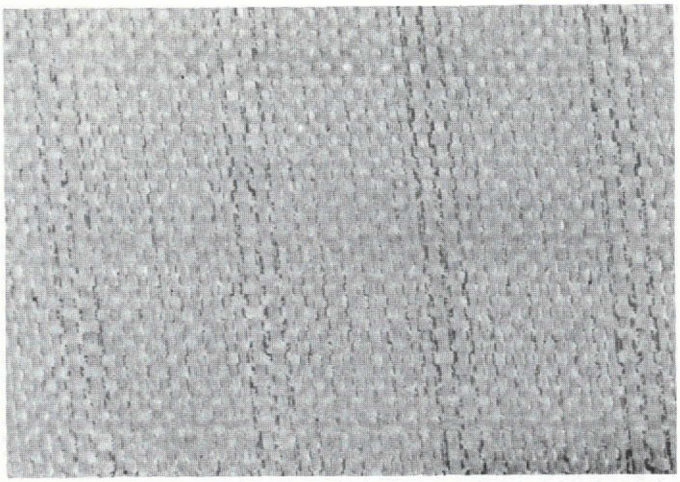


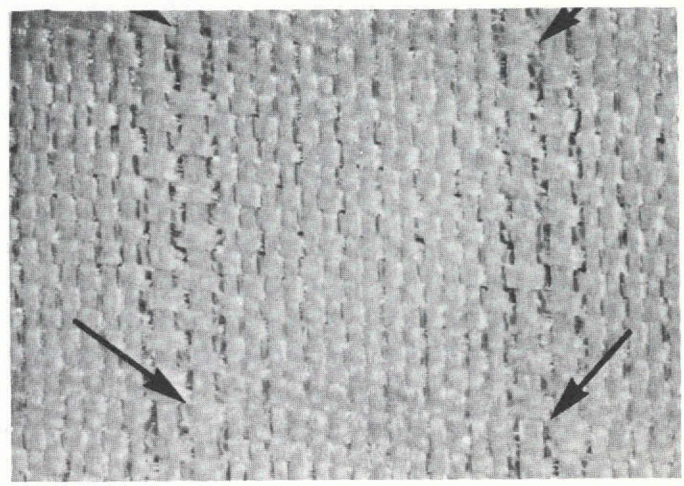
Figure 1. The Skylab spacecraft with two thermal shields installed in orbit after the meteoroid shield and one solar paddle were torn off during a launch mishap. The rectangular shield of white-painted 200-μm sail material is on top. Two corners of the shield made of orange 75-μm parasol material, installed earlier, are visible.

vacuum (1.33 X 10^{-4} N/m^2 ($\approx 10^{-6}$ torr)) over a 24-hour period with a substrate temperature of 398 K (125°C) and a collector temperature of 298 K (25°C). Acceptable polymeric materials are those which exhibit a total weight loss of 1 percent or less and a volatile condensable materials profile of 0.1 percent or less. These outgassing results are presented below.

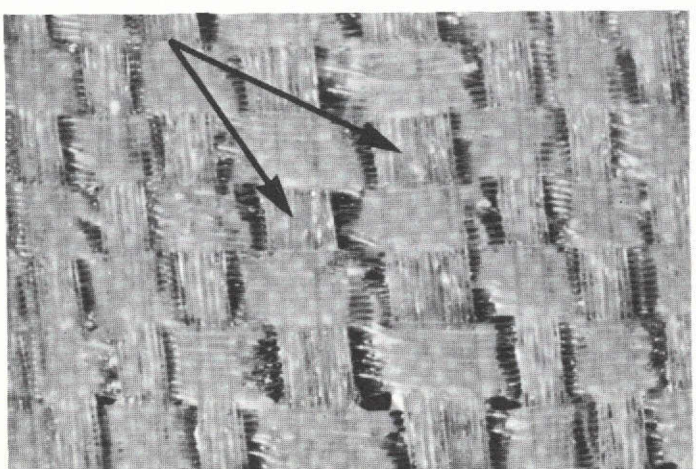
Material	Total Weight Loss, Percent	Volatile Condensable Materials, Percent
Parasol	1.024	0.012
Sail	0.970	0.220
S-13-G Paint	0.795	0.229



Top, 7X magnification. Note the 0.36 cm (0.14-inch) square grid pattern, framed by two heavier yarns.



Center, 14X magnification. One of the grids, with corners marked by arrows.



Left, 44X magnification. This shows the two sizes of yarn with the two heavier yarns, indicated by arrows, running vertically.

Figure 2. Three magnifications of the 75-μm orange-colored nylon parasol material, showing the weave and nature of the pattern. The warp direction is vertical in the photographs.

These tests indicated that the parasol material was marginally acceptable, and that the sail material was <u>not</u> acceptable, due to its relatively high 0.22-percent VCM. A sample of the white paint was stripped from the nylon and also tested, and it was evident that this paint was the predominant contributor to the observed high VCM exhibited by the sail material.

ULTRAVIOLET THERMAL VACUUM TEST

In addition to the outgassing tests, other samples of both parasol and sail materials were exposed to varying levels of UV radiation in a thermal vacuum chamber, in order to simulate the space environment. In all exposures a xenon solar simulator was utilized, with the incident intensity approaching maximum values of 2.5 solar constants. Sample temperature was maintained below the specified 393 K (120°C) limit throughout the test.

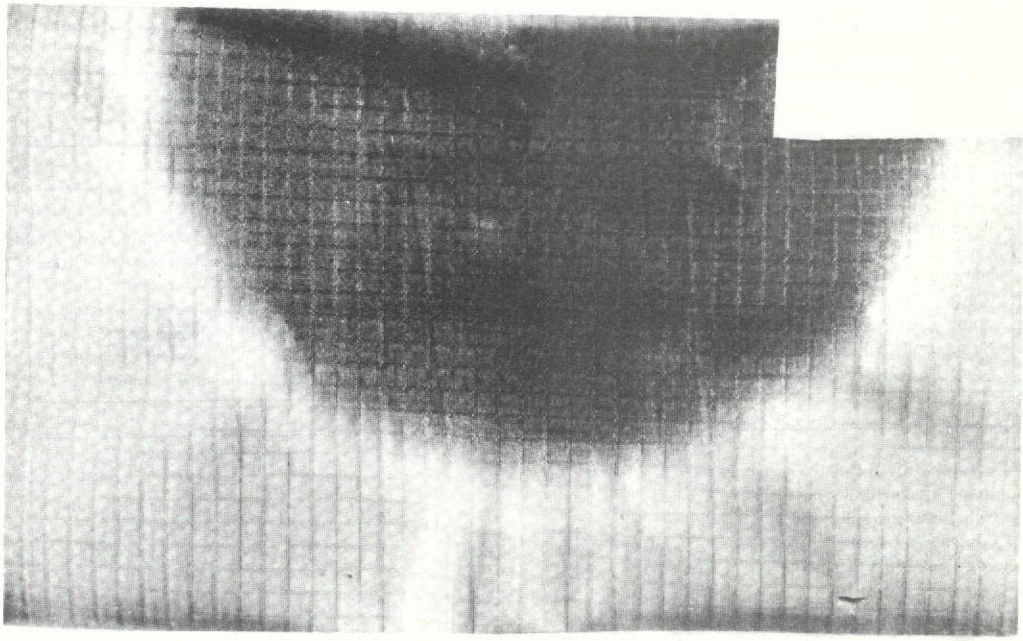
After receiving the prescribed amounts of UV exposure measured in equivalent sun hours (ESH), samples of the two materials were removed periodically for evaluation of their mechanical properties. Optical property determinations were performed by the Engineering Applications Branch, GSFC.

Figure 3 shows one of the parasol material samples after an exposure of 2350 ESH, as it was received from the thermal vacuum chamber and just prior to being cut into tensile test samples. The appearance is typical of the parasol material; the circular, irradiated zone shows the extent of the discoloration as viewed from the irradiated, orange nylon side. The irradiated zone indicates the peripheral gradation produced by the UV source. Sail material samples were similarly exposed, on the white paint side, which was laminated to the orange nylon. No visually detectable discoloration was evident in the sail material.

TENSILE TESTS

The segments exposed to the UV radiation were subdivided into strips 2.54 cm (one inch) wide, as indicated in figure 2. Similar samples were cut from all submitted materials in both the machine (warp) and transverse (woof or filled) directions. The static tensile tests were made with a testing machine, operating at a constant crosshead speed of 0.508 cm (0.20 inch) per minute. The 5.08-cm (two-inch) gage sections, lettered A, B, and C, are the parts actually pull tested in the machine. Total elongation over the original gage length was obtained for all samples, with ultimate breaking load determined in newtons per cm width. In this same sample, sections A and B appeared to be more uniformly irradiated, while section C received the least amount of radiation.

Static tensile results for the parasol and sail materials are presented in tables 1 and 2, respectively. Graphical plots of the parasol data are presented in figures 4 and 5 and sail data are presented in figures 6 and 7.



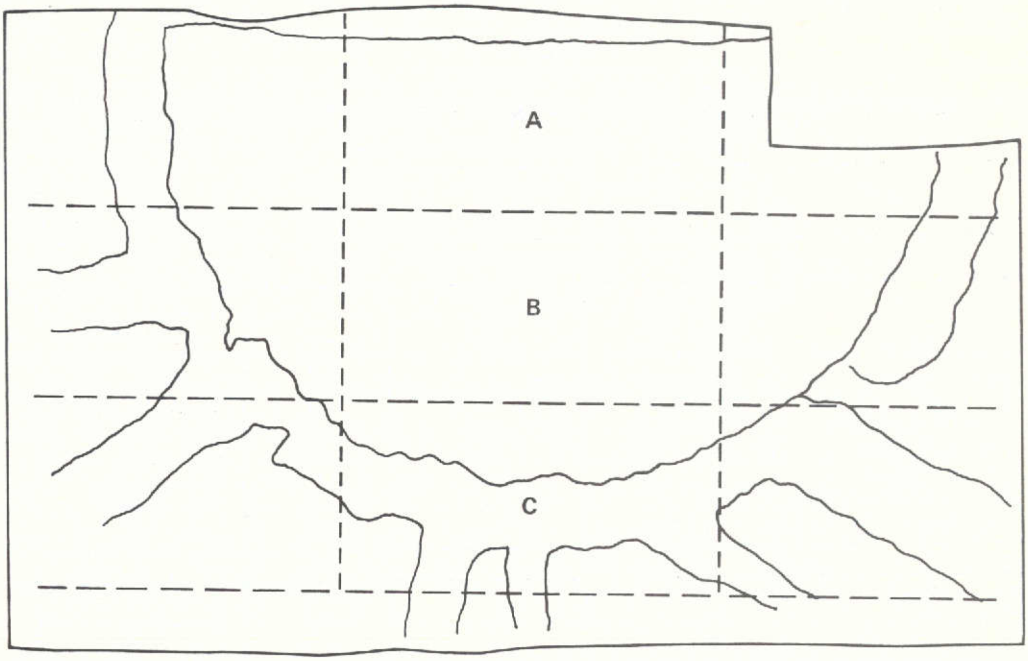


Figure 3. The darkened irradiated zone of the 75-μm parasol material after 2,350 equivalent sun hours of UV radiation in vacuum (full size). Below, the method in which test strips were cut lengthwise from the irradiated area. The A, B, C areas were the parts pull tested.

Table 1

Static Tensile Properties, 75-μm (3-mil) Skylab Fabric, Parasol Material

Condition	Test Temperature °K (°C)	Breaking Load Newtons/cm width	Elongation* (%)	Remarks
MACHINE DIRECTION				
As received	296 (23)	93.5	27.8	Average of 3 samples
Control**, 400 VEH	296 (23)	89.7	27.6	Average of 4 samples
Nylon irradiated, 400 ESH	296 (23)	65.8	20.1	Average of 3 samples
Control, 709 VEH	296 (23)	86.7	27.3	Average of 4 samples
Control, 709 VEH	173 (–100)	126.1	25.0	Single sample
Nylon irradiated, 709 ESH	296 (23)	46.2	15.4	Average of 2 samples
Nylon irradiated, 709 ESH	173 (–100)	49.9	9.0	Single sample
TRANSVERSE DIRECTION				
As received	296 (23)	97.2	35.8	Average of 3 samples
Control, 365 VEH	296 (23)	94.7	36.1	Average of 3 samples
Nylon irradiated, 365 ESH	296 (23)	79.3	26.1	Average of 3 samples
Nylon irradiated, 365 ESH	173 (–100)	71.8	10.0	Single sample
Control, 709 VEH	173 (–100)	143.6	30.0	Single sample
Control, 2350 VEH	296 (23)	93.9	34.5	Average of 2 samples
Control, 2350 VEH	173 (–100)	118.0	21.8	Single sample
Nylon irradiated, 2350 ESH	296 (23)	59.2	20.6	Average of 2 samples
Nylon irradiated, 2350 ESH	173 (–100)	57.4	7.8	Single sample

*Elongation was determined from a 5.08 cm gage length.
**Control Sample: Sample was cut from material exposed to vacuum but not irradiated.
ESH = Equivalent Sun Hours
VEH = Vacuum Exposed Hours

Table 2

Static Tensile Properties, 200-μm (8-mil) Skylab Fabric, Sail Material

Condition	Test Temperature °K (°C)	Breaking Load Newtons/cm width	Elongation* (%)	Remarks
MACHINE DIRECTION				
As received	296 (23)	78.8	23.9	Average of 4 samples
Mylar irradiated, 50 ESH	296 (23)	80.4	25.7	Average of 3 samples
Mylar irradiated, 100 ESH	296 (23)	80.6	23.6	Average of 3 samples
Paint irradiated, 400 ESH	296 (23)	85.5	26.0	Average of 2 samples
Control**, 400 VEH	296 (23)	82.3	25.0	Single sample
Control, 1920 VEH	296 (23)	89.0	27.0	Single sample
Control, 1920 VEH	173 (–100)	113.8	17.9	Single sample
Paint irradiated, 1920 ESH	296 (23)	80.7	26.5	Single sample
Paint irradiated, 1920 ESH	173 (–100)	90.2	12.2	Single sample
TRANSVERSE DIRECTION				
Paint irradiated, 400 ESH	296 (23)	90.7	43.0	Average of 2 samples
Control, 400 VEH	296 (23)	92.5	45.0	Single sample
Control, 1920 VEH	296 (23)	92.5	41.4	Single sample
Control, 1920 VEH	173 (–100)	131.3	25.6	Single sample
Paint irradiated, 1920 ESH	296 (23)	88.6	40.8	Average of 2 samples
Paint irradiated, 1920 ESH	173 (–100)	96.7	17.8	Single sample

*Elongation was determined from a 5.08 cm gage length.
**Control Sample: Sample was cut from material exposed to vacuum but not irradiated.
ESH = Equivalent Sun Hours
VEH = Vacuum Exposed Hours

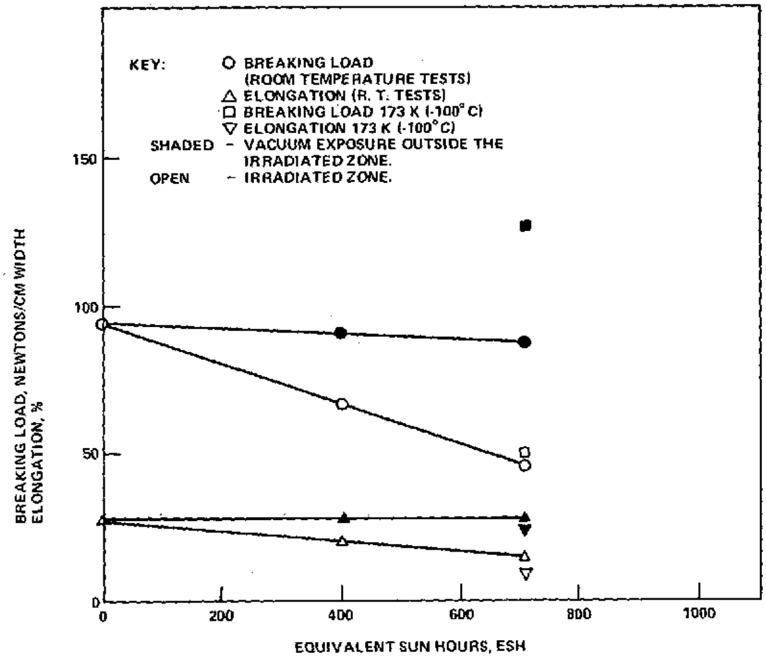


Figure 4. Tensile test results of Skylab's parasol material, machine direction, compared with exposure to UV radiation.

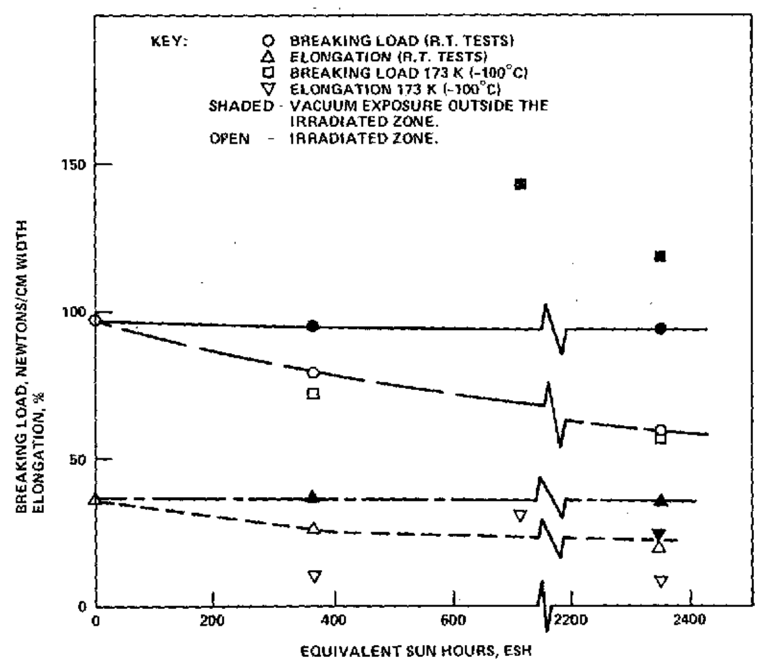


Figure 5. Tensile test results of Skylab's parasol material, transverse direction, compared with exposure to UV radiation.

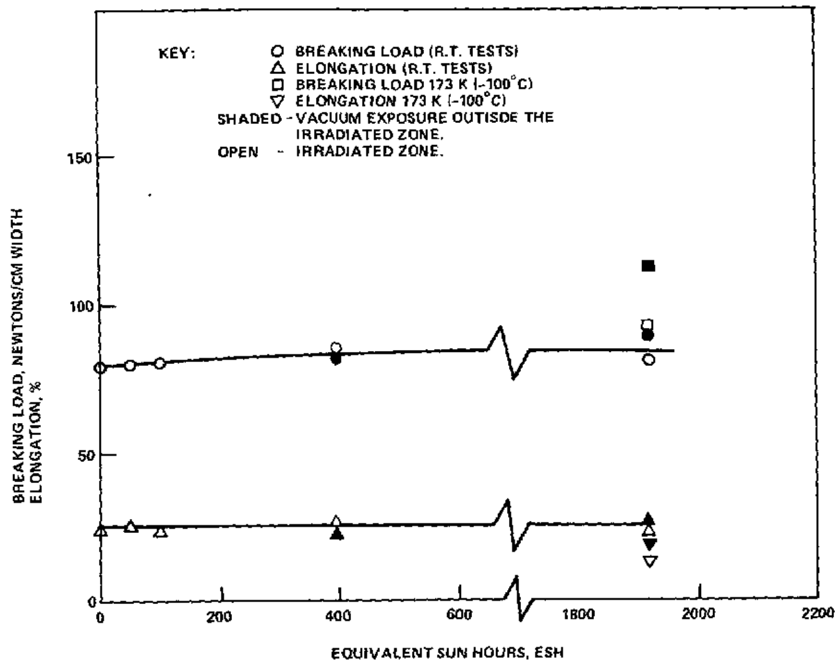


Figure 6. Tensile test results of Skylab's sail material, machine direction, compared with exposure to UV radiation.

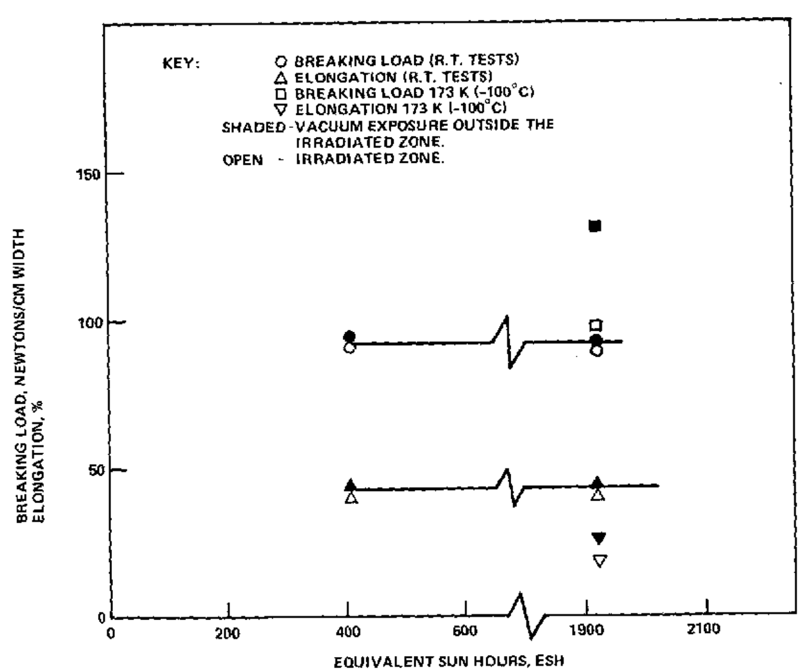


Figure 7. Tensile test results of Skylab's sail material, transverse direction, compared with exposure to UV radiation.

As indicated in figures 4 and 5, the parasol laminate showed a decrease in ultimate tensile strength after being irradiated from the orange nylon side. This strength reduction became greater with time of exposure in both the machine and transverse directions. Strength reductions at room temperature for the machine direction totaled 51 percent after 709 ESH and 39 percent after 2350 ESH for the transverse direction.

Elongation of the parasol samples also decreased as the irradiation exposure time increased. As would be expected, the elongation was greater in the transverse direction than in the machine direction. This is explained in part by the weaving pattern employed; the warp fibers are essentially held taut in contrast to the fill fibers, which in their undulating pattern travel a greater distance and hence are longer per unit fabric length. The elongation measurements for the machine direction decreased 45 percent after 709 ESH, and for the transverse direction 42 percent after 2350 ESH.

In the case of the sail laminate, figures 6 and 7 show that little change in strength or elongation was noted throughout the 1920 ESH exposure. Samples of this material were irradiated from the mylar side as well as from the white paint side. Nominal breaking strength levels are 82 and 91 N/cm width (47 and 52 pounds/inch width), and total elongation values are 25 percent and 43 percent, respectively, for the machine and traverse directions.

LOW TEMPERATURE TESTS

Limited low temperature tests were also performed at 173 K (-100°C) on both thermal shield materials. Samples were prepared in both weave directions, that is, in the machine and transverse directions.

In general, substantial increases in breaking strengths with corresponding decreases in elongation were observed at the low temperatures, in comparison to the room temperature values. These limited results suggest also that the low temperature properties are detrimentally affected by long term irradiation. Values given in tables 1 and 2 show that for each sample irradiated the strength and elongation dropped. The change was greater for the parasol material than for the sail material.

CONCLUSIONS

1. Tensile strength of the as-received parasol material was unaffected by sample orientation. There was a modest difference in elongation values, which was attributed to the nature of the orange nylon weave pattern.

2. Irradiation significantly affected the mechanical properties of the parasol material. Strength and ductility continued to decline with increased exposure times, this reduction being in the order of 40 percent after 2350 ESH in the transverse direction. Earlier tests showed a 50-percent reduction in the machine direction after 709 ESH.

3. Temperature has a significant effect on the strength properties of both materials, lower temperatures in general strengthening the materials. Irradiated samples appeared to be more affected by low temperature than samples not subjected to UV radiation.

4. The influence of vacuum on both laminate materials appeared to be negligible regardless of sample orientation.

5. Mechanical properties of the sail material in both orientations remained essentially unchanged after exposure.

6. The unirradiated but vacuum-exposed sail material appeared to exhibit more mechanical anisotropy than did the parasol material. Transverse strength of the sail material was about 12 percent higher than the value measured in the machine direction. Similarly, transverse elongation was about 44 percent greater than machine direction elongation.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland June 26, 1974
602-41-75-01-51

NASA-Langley, 1974